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PTJ North

NEXTGEN CEMENT DEVELOPMENT

Introduction

Concrete and its varied components have been used for infrastructure construction for 2,500+ years with varying levels of success. The Roman Empire innovated a hydraulic concrete formula that worked for their infrastructure needs especially well and those infrastructure works are still in use today – 2,500 years later. Our own contemporary formula's do not typically work as well and last for roughly 30 – 100 years. Answering "what", "why" and "how" to relearn this apparent lost technology and allow our modern infrastructure needs to capture the longevity of the old formula using contemporary components for least cost, least risk is the intent of this simple paper.

Background

Answering some basic questions about definitions for what concrete is and distinctions for its components that are in common use (by others).

An excerpt from: Hossain, Khandaker M. Anwar. "Properties of volcanic pumice based cement and lightweight concrete." *Cement and concrete research* 34, no. 2 (2004): 283-291. Plus also: Hydraulic Cements

"Definition of concrete, hydraulic cement, mortar, and grout

Q. What are concrete, hydraulic cement, mortar, and grout?

A. *Concrete* is a composite material that consists of a mixture of hydraulic cement, aggregates, and water, with or without admixtures, fibers, or other cementitious materials.
Hydraulic cement is cement that sets and hardens by chemical reaction with water (hydration) and is capable of doing so under water (ACI 225R). The hydration reactions result in the formation of a hard-solid mass. The most widely used hydraulic cement is Portland cement. Other kinds of hydraulic cement include blended cements and ground granulated blast-furnace slag (ACI 233R). Pozzolans, both natural (ACI 232.1R) and artificial (fly ash, ACI 232.2R, and silica fume, ACI 234R) are often used as a cementitious ingredient of concrete.
Mortar is a mixture of cement paste and fine aggregate; in fresh concrete, the material occupying the interstices among particles of coarse aggregate; in masonry construction, joint mortar may contain masonry cement, or may contain hydraulic cement with lime (and possibly other admixtures) to afford greater plasticity and workability than are attainable with standard Portland cement mortar.
Grout is a mixture of cementitious materials and water, or other binding medium, with fine aggregate.

References: SP-1(02); CT-18; ACI 225R-19; ACI 233R-03; ACI 232.1R-12; ACI 232.2R-03; ACI 234R-06; E-1(16); E3-13
Topics in Concrete: Concrete Fundamentals; Grout; Materials"

Then answering the question of "why" modern concrete fails so badly (by others):

The cracks are starting to show. Dean McCartney, Author provided

The problem with reinforced concrete

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By itself, concrete is a very durable construction material. The magnificent Pantheon in Rome, the world's largest unreinforced concrete dome, is in excellent condition after nearly 1,900 years. And yet many concrete structures from last century – bridges, highways and buildings – are crumbling. Many concrete structures built this century will be obsolete before its end.

Given the survival of ancient structures, this may seem curious. The critical difference is the modern use of steel reinforcement, known as rebar, concealed within the concrete. Steel is made mainly of iron, and one of iron's unalterable properties is that it rusts. This ruins the durability of concrete structures in ways that are difficult to detect and costly to repair.

While repair may be justified to preserve the architectural legacy of iconic 20th-century buildings, such as those designed by reinforced concrete users like Frank Lloyd Wright, it is questionable whether this will be affordable or desirable for the vast majority of structures. The writer Robert Courland, in his book Concrete Planet, estimates that repair and rebuilding costs of concrete infrastructure, just in the United States, will be in the trillions of dollars – to be paid by future generations.

Old bridges need new money to replace. Phil's 1stPix/Flickr.com, CC BY-NC

Steel reinforcement was a dramatic innovation of the 19th century. The steel bars add strength, allowing the creation of long, cantilevered structures and thinner, less-supported slabs. It speeds up construction times, because less concrete is required to pour such slabs.

These qualities, pushed by assertive and sometimes duplicitous promotion by the concrete industry in the early 20th century, led to its massive popularity.

Reinforced concrete competes against more durable building technologies, like steel frame or traditional bricks and mortar. Around the world, it has

replaced environmentally sensitive, low-carbon options like mud brick and rammed earth – historical practices that may also be more durable.

Early 20th-century engineers thought reinforced concrete structures would last a very long time – perhaps 1,000 years. In reality, their life span is more like 50-100 years, and sometimes less. Building codes and policies generally require buildings to survive for several decades, but deterioration can begin in as little as 10 years.

Many engineers and architects point to the natural affinities between steel and concrete: they have similar thermal expansion characteristics, and concrete's alkalinity can help to inhibit rust. But there is still a lack of knowledge about their composite qualities – for example, in regard to sun-exposure-related changes in temperature.

The many alternative materials for concrete reinforcement – such as stainless steel, aluminium bronze and fibre-polymer composites – are not yet widely used. The affordability of plain steel reinforcement is attractive to developers. But many planners and developers fail to consider the extended costs of maintenance, repair or replacement.

Cheap and effective, in the short term at least. Luigi Chiesa/Wikimedia Commons, CC BY-SA

There are technologies that can address the problem of steel corrosion, such as cathodic protection, in which the entire structure is connected to a rust-inhibiting electric current. There are also interesting new methods to monitor corrosion, by electrical or acoustic means.

Another option is to treat the concrete with a rust-inhibiting compound, although these can be toxic and inappropriate for buildings. There are several new non-toxic inhibitors, including compounds extracted from bamboo and bacterially derived "biomolecules".

Fundamentally, however, none of these developments can resolve the inherent problem that putting steel inside concrete ruins its potentially great durability.

The environmental costs of rebuilding

This has serious repercussions for the planet. Concrete is the third-largest contributor to carbon dioxide emissions, after automobiles and coal-fuelled power plants. Cement manufacturing alone is responsible for roughly 5% of

global CO_2 emissions. Concrete also makes up the largest proportion of construction and demolition waste, and represents about a third of all landfill waste.

Recycling concrete is difficult and expensive, reduces its strength and may catalyse chemical reactions that speed up decay. The world needs to reduce its concrete production, but this will not be possible without building longer-lasting structures.

Rebar reclamation: an expensive job. Anna Frodesiak/Wikimedia Commons

In a recent paper, I suggest that the widespread acceptance of reinforced concrete may be the expression of a traditional, dominant and ultimately destructive view of matter as inert. But reinforced concrete is not really inert.

Concrete is commonly perceived as a stone-like, monolithic and homogeneous material. In fact, it is a complex mix of cooked limestone, clay-like materials and a wide variety of rock or sandy aggregates. Limestone itself is a sedimentary rock composed of shells and coral, whose formation is influenced by many biological, geological and climatological factors.

This means that concrete structures, for all their stone-like superficial qualities, are actually made of the skeletons of sea creatures ground up with rock. It takes millions upon millions of years for these sea creatures to live, die and form into limestone. This timescale contrasts starkly with the life spans of contemporary buildings.

Steel is often perceived to be inert and resilient too. Terms such as “Iron Age” suggest an ancient durability, although Iron Age artefacts are comparatively rare precisely because they rust. If construction steel is visible, it can be maintained – for instance, when the Sydney Harbour Bridge is repeatedly painted and repainted.

However, when embedded in concrete, steel is hidden but secretly active. Moisture entering through thousands of tiny cracks creates an electrochemical reaction. One end of the rebar becomes an anode and the other a cathode, forming a “battery” that powers the transformation of iron into rust. Rust can expand the rebar up to four times its size, enlarging cracks and forcing the concrete to fracture apart in a process called spalling, more widely known as “concrete cancer”.

Concrete cancer: not pretty. Sarang/Wikimedia Commons

I suggest that we need to change our thinking, to recognise concrete and steel as vibrant and active materials. This is not a case of changing any facts, but rather of re-orientating how we understand and act on those facts. Avoiding waste, pollution and needless rebuilding will require thinking well beyond disciplinary conceptions of time, and this is especially true for the building and construction industries.

The collapsed civilisations of the past show us the consequences of short-term thinking. We should focus on building structures that stand the test of time – lest we end up with hulking, derelict artefacts that are no more fit for their original purpose than the statues of Easter Island."

Nextgen Development Concept

Capturing the high performance (tensile, compression and deformation strength) of the Roman Empire's hydraulic cement matrix which cured readily in saltwater and also capturing our current society's need for a terrestrial and marine cement ability can seem really hard to do because nobody's apparently come close.

In a strong sense I am asking to find the way to increase our version of concrete's strength using commonly available components and I also do not want to use reinforcing rod (re-rod) steel because of its corrosion issues. A very tall order but I do think it can be done with an open mind and some perseverance.

A number of very recent studies have been done that point the way. Not one of them offers an integrated recipe or formula to follow. I really don't understand why that might be the case but can certainly make a guess.

I've assembled a "recipe" with some broad instructions that should be helpful (I hope so). Not least the recipe will yield a cement matrix that will perform at least as well as today's cement. I strongly suspect it will outperform it and may well offer a least cost, least risk solution along with my own take on IP that might be captured as well.

That recipe is below:

- Aligned carbon nanotubes should be used - whether MW or SW will make no difference (Insight).
- Quicklime (CaO) shall be used as the hydrated cement' primary binder.
- Water shall be used as the hydration agent.
- Aluminum shall be used as a water supplement to promote tobermorite formation as sodium aluminum phosphate (Insight).
- Water shall not be softened (Insight).
- Water as the matrix or hydration agent or solution shall be alkaline and preferably with a pH of 8 +/- 0.5 in its initial state before any blending (Insight).
- Water shall be visually free of organic contaminants.
- Alignment of carbon nanotubes shall be done by mechanical mixing in water after the surfactant addition (Insight).
- Carbon nanotubes shall be added in the range of 0.1 - 0.5% by overall weight of the final mixture and preferably in the 0.1 - 0.25% range (Insight).
- Dispersion of the carbon nanotubes (CNT) shall be accomplished by inducing hydrophilicity of the CNT with a small applied voltage of 2.0V to the initial water / CNT mix with phase and wattage not important (Insight).
- Alignment of the CNT in the initial water mix must be done by mechanical mixing until visually thoroughly dispersed (Insight).
- Use of oxidized calcium sulfate as an additive to the cement binder' dry blend is contraindicated (Insight).
- The soluble aluminum salt as sodium aluminum phosphate shall be added to the initial water blend before the CNT addition (Insight).
- Aggregate type and size used shall be to common standard.

- Aggregate used must be pre-washed until free of visible dirt and organic contaminants and then blended into the cement binder.
- Use of a non-ionic surfactant should be added to manufacturer' specification before the addition of the aluminum salt and CNT to the water matrix solution (Insight).
- Concrete cure time will be to industry standard for time and temperature.
- Mechanical performance shall be similar to hydraulic concrete or better without the need for continuous wetting unless in an arid climate (Insight).
- Otherwise industry standards for mix blends and mixing time and energy shall not change.
- Water soluble iron salts such as iron sulfate or thirdly ferrous iron may be used as a substitute for calcium aluminum phosphate in extraordinary circumstances such as extremely arid or near vacuum environments (Insight).